Title: Drinking water quality and well owner perceptions of quality in a rural watershed in British Columbia, Canada.

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Keywords: Drinking Water, Groundwater, Nitrate, Agriculture, Urbanization, Perception

Abstract

In rural areas individual well owners have little control over their drinking water quality, which can be influenced by geological factors and adjacent land use. Analysis of groundwater used for drinking in a rural watershed with mixed land use in British Columbia, Canada, showed that although most samples did not exceed guidelines designed to protect human health, those that did were concentrated in urbanising areas. With the help of local volunteers, 75 groundwater samples were collected in the Hatzic Valley, located in the Lower Fraser Valley area of British Columbia. Collection and analysis occurred twice, once in July 2002 and again in March 2003. A spatial database was created and the percentages of four predominant land uses were calculated within several radii of the wells sampled. Two wells exceeded the health standard for nitrate-N and 10 more had nitrate-N levels above 3 mg/L (considered indicative of land use impacts). All the wells with elevated NO_3-N were shallow (less than 10 m deep). Percent forest cover surrounding the wells was negatively correlated with nitrate level, while percent urbanised land was positively related to nitrate. The cause of high nitrate in the urban areas is thought to be from septic systems. A questionnaire study revealed that the majority of local residents perceived their water quality to be good or excellent. The residents base their perceptions on tangible indicators rather than chemically determined ones. The negative perceptions were correlated with the presence of high levels of iron and manganese rather than nitrate.

Keywords Drinking Water, Groundwater, British Columbia, Nitrate, Iron, Perception, Agriculture, Urbanization, Hatzic Valley, Lower Mainland

Introduction

Groundwater is the primary source of drinking water for 30% of Canadians, many of whom live in rural areas where they rely on private wells to supply their water needs (Environment Canada, 2004). Groundwater is an attractive option for rural homeowners because it is often of high quality and more broadly distributed than surface water supplies (Summers and FitzGibbon, 2003).

The fundamental characteristics of groundwater are determined by its source. The parent material through which it flows determines parameters such as hardness and in many cases odour and colour. In addition to determining basic properties of the water, the substrate through which groundwater moves acts as a natural filter for many contaminants and pathogenic micro-organisms. Because of this natural filtering action, groundwater has traditionally been considered less prone to contamination than surface water (Rudolph, 1998). However, the capacity of the ground to act as a filter for water is a function of several factors, including characteristics of the soil and underlying bedrock, and the nature and concentration of potential pollutants entering the system. These natural processes have limits that can be stressed to the point that they cease to function, leading to groundwater contamination (Summers and FitzGibbon, 2003; Jaffe and DiNovo, 1997; O'Connor, 2002).

Certain land uses can increase the vulnerability of groundwater to contamination. For example, the Lower Fraser Valley area of British Columbia, Canada is an area where agriculture is practiced intensively as well as an area where groundwater use is high. Several aquifers in this area are known to be contaminated with nitrate (Schreier *et al*., 1996 and Liebscher *et al*., 1992). Nitrate (NO_3^-) is a highly soluble nitrogen anion that is not usually adsorbed to soil particles. (The terminology Nitrate-N is used to refer to only the nitrogen in the NO_3 molecule when discussing levels of nitrate in groundwater; however, throughout this article, the term nitrate is used interchangeably with nitrate-N when referring to specific measurements of this nutrient.) Supplying crops with adequate nitrogen is vital for productivity; however, addition of nitrogen fertilizer or manure to farm fields in excess of that required for crops will result in loss of nitrate from the root zone by leaching (Follett, 1989). Nitrate can also enter groundwater through leaching from improperly maintained septic systems. The maximum allowable concentration (MAC) for nitrate in the Guidelines for Canadian Drinking Water Quality (GCDWQ) is 10 mg/L nitrate as nitrogen. However, since background levels of nitrate in groundwater are generally less than 2 mg/L we use 3 mg/L as an indication that the groundwater has been impacted or is under the influence of surface water (Coote and Gregorich, 2000; Schreier *et al.,* 1996; Carmichael *et al.,* 1995).

Rural homeowners with private wells often have no control over the land use adjacent to their property. They also, typically, have high faith in the quality of the water from their wells. Most rural homeowners do not treat their drinking water and rely solely on the integrity of their drinking water sources to protect them from disease (Jaques and Rhode 2001; Summers and FitzGibbon, 2003; Legault, 2000). They tend not to treat their water even in cases when the wells have known water quality problems. A study of deterioration of well water environments in Alberta found that "although about 74% of the active wells were reported to have water quality and/or quantity problems, only 31% of these wells were identified as ever having received a treatment…" (Legault, 2000). In addition to rarely treating their drinking water, rural homeowners tend not to test their water for contaminants. This is also a result of the confidence that most rural homeowners have in their water source. Using groundwater quality data, land use data and data from a questionnaire, this paper examines the interactions between land use, water quality and perception of quality.

Study Location

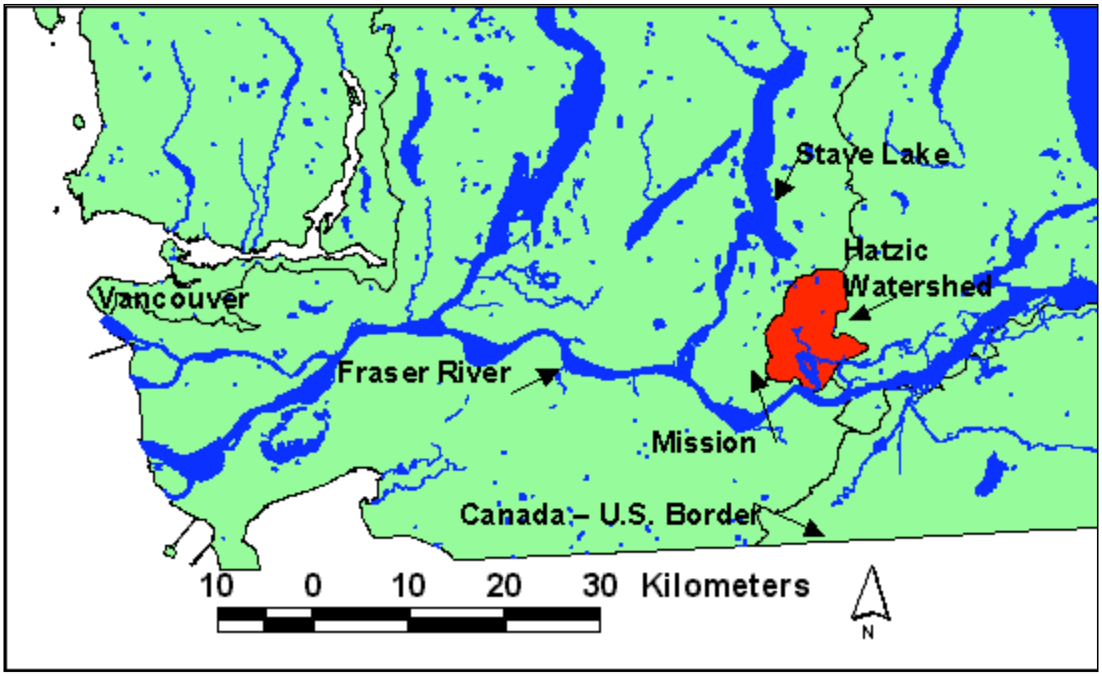

Figure 1. Location of the Hatzic Watershed within the Lower Mainland of British Columbia, Canada.

Field work for this project was conducted in the Hatzic watershed, which is located about 75km east of Vancouver on the North Side of the Fraser River, in British Columbia, Canada (see figure 1). The watershed is about 8730 ha in size. Samples for this project were taken from the valley bottom, within an area about 3100 ha in size. The area has mixed land use including land used for agriculture, forested land and densely populated rural subdivisions. The forested land is clustered to the north of the valley with the agriculture dominating the centre and the south and small subdivisions on Hatzic Island rounding out the remainder of the land use. The area is crossed by several streams which originate in the mountains surrounding the valley and drain through Hatzic Lake into the Fraser River. Hatzic Lake, a former meander in the Fraser River, is the predominant geographical feature in the area. Many residents of the area use groundwater as their main source of water although the local streams are also used.

Materials and Methods

Data Collection

Three types of data were collected and analyzed in the study:

1) Groundwater quality was determined by water quality analysis of samples provided by individual households throughout the Hatzic Valley watershed. Seventy-five samples were collected with the help of local volunteers in July 2002 and again in March 2003. Random households from throughout the study area were invited to participate in the program and those who agreed received sampling bottles with detailed instructions that were later collected by the volunteers. After collection, the samples were analyzed for pH; conductivity; nitrate-N and orthophosphate; and

a suite of 21 elements which included aluminium, arsenic, boron, barium, calcium, cadmium, cobalt, chromium, copper, iron, potassium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, selenium, silicon, strontium and zinc.

2) Spatial data used for analysis included orthophotos and other digital maps provided by the Fraser Valley Regional District (FVRD). The land use was divided into four major categories; forested, urban, agricultural and rural residential (non-forested land surrounding houses not in subdivisions but not used for agriculture) and mapped using Arc View 3.2, a geographical information system (GIS). The approximate location of each well was plotted based on the location of the house on each property (houses were located based on visual inspection of orthophotos and the other maps). Circles with radii of 50, 100 and 200m were plotted around each well and the percentage of each land use within each radius was calculated using the GIS.

3) A survey questionnaire was distributed with the sample bottles in order to learn the opinions of those who provided groundwater samples. Answers to the survey questions were used to learn more about the wells as well as the perceptions of the people whose wells were sampled.

Within the study area there are three distinct aquifers described by Carmichael et al. (1996) (see figure 2.). Water samples for the project were taken from each aquifer. In the case of AQ1, the Nicomen Slough Aquifer, only the portion of the aquifer within the Hatzic Watershed was studied (see figure 2.).

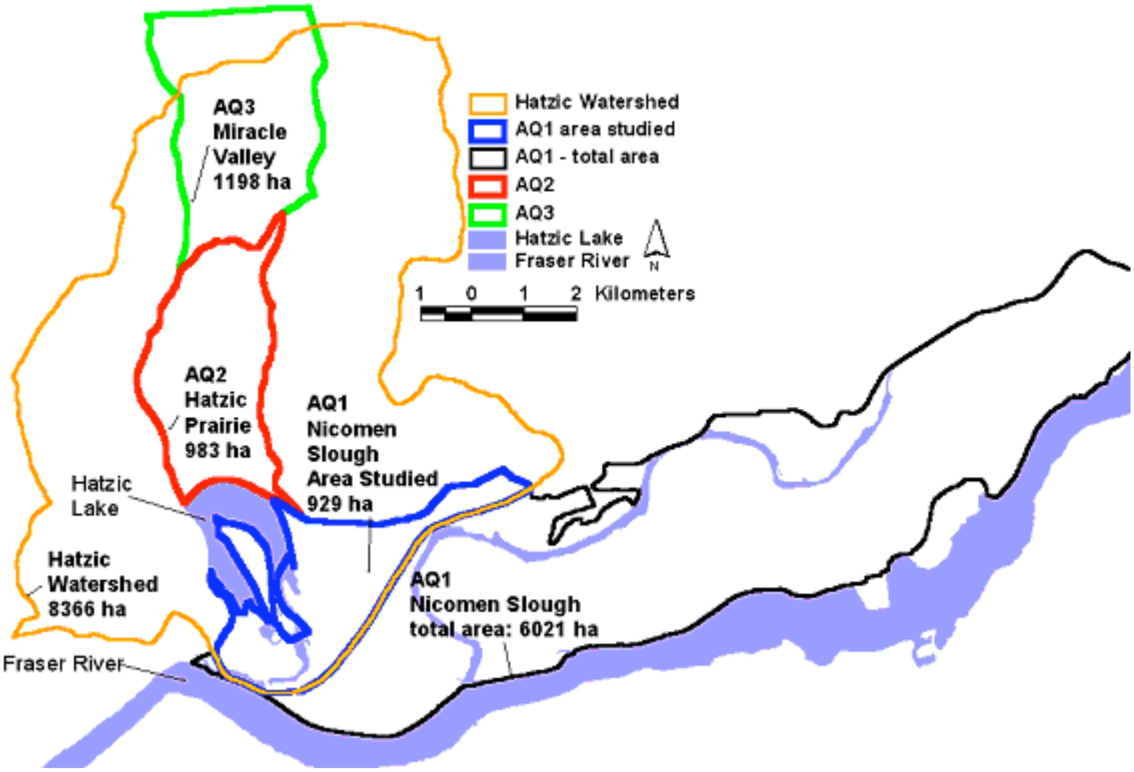

Figure 2. Location of the three aquifers studied. The watershed boundary is also included for reference.

Analysis

Data analysis was performed using non-parametric statistical techniques. These methods, although less powerful than traditional techniques, are useful when the assumptions of parametric procedures are not met. In this case these techniques were used because the data was not normally distributed and some of the data to be analyzed was ordinal in nature rather than continuous (Siegel, 1956). Non-parametric procedures compare population medians rather than population means. Spearman's Rank Correlation coefficients (r) were calculated in order to summarize the strength and direction (negative or positive) of the relationship between two variables. This test was used when comparing results throughout the watershed such as the comparison of individual water quality parameters with water quality perception. The Mann-Whitney U test, the non-parametric alternative to the unpaired t-test, was used in situations where parameters had been split into two groups (for example summer and winter) and it was necessary to test if the groups were significantly different from each other. The Kruskal-Wallis (K-W) test, the non-parametric equivalent

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to the analysis of variance (ANOVA), was used to test for significant differences between three or more groups (for example the differences between aquifers). See Magwood (2004) for a more detailed description of the methods and analysis.

Results
Water Quality

As mentioned above, preliminary research showed that although the area studied was part of a single watershed there were three distinct aquifers within the area (Carmichael et al, 1996). The southernmost aquifer, the Nicomen Slough aquifer (AQ1), had water quality that was significantly different (based on Kruskal-Wallis test results) for many parameters than the other two aquifers. This indicated that the substrate of AQ1 was quite different than that of the Hatzic Prairie Aquifer (AQ2) and the Miracle Valley Aquifer (AQ3) (see figure 2 for locations of aquifers within the study area). Parameter levels that were significantly different in AQ1 included silicon and calcium, neither of which are generally considered to be influenced by land use, and conductivity, which can be influenced by both land use and geology. Although the preceding results showed that AQ1 was chemically different from AQ2 and AQ3, AQ1 and AQ2 were more physically similar, as both are shallow and unconfined, whereas AQ3 is a deeper confined aquifer.

Land use was not evenly distributed throughout the valley. Agriculture (39% of the valley area) dominated the central and southeastern portion of the valley (AQ1 and AQ2), whereas the north (AQ3) was largely covered with forest (37% of the valley). Dense residential areas represented a much smaller portion of the total area (0.7%) and were found in three small subdivisions on Hatzic Prairie (AQ2) (the central valley) and in several subdivisions and trailer parks on Hatzic Island (AQ1). The uplands to the east and west were largely forest covered and uninhabited due to the steepness of the slopes.

Of the parameters measured, nitrate was the only one to exceed a Maximum Allowable Concentration (MAC) as set out in the Guidelines for Canadian Drinking Water Quality (GCDWQ) although there were several parameters that exceeded aesthetic objectives (AOs). Two wells exceeded the MAC for nitrate, one in winter and one in summer. Ten other wells had nitrate levels above 3 mg/L in either summer, winter or both indicating that the water in these wells has been impacted by activities on the land's surface. Several studies have reported that shallower wells often show higher nitrate levels than deeper wells (Schreier *et al.,* 1996; Hudak, 1999; Burkart and Stoner, 2002; Muhammetoğlu *et al.,* 2002; Reid *et al.,* 2002). The results of this study (illustrated in figure 3) showed that there were no wells deeper than 10 m in which nitrate levels exceeded 3 mg/l.

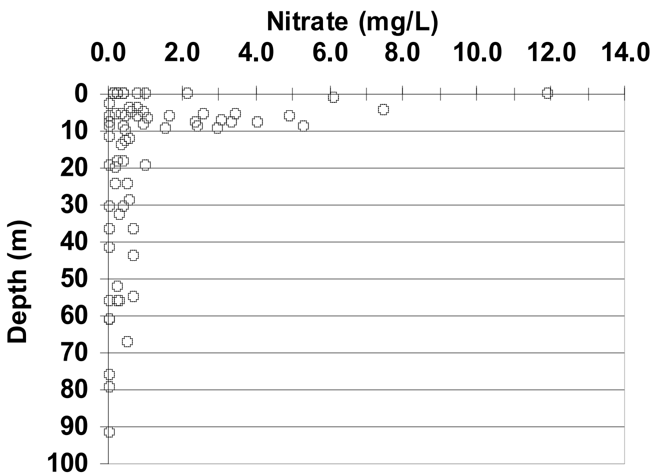

Figure 3. Relationship between Nitrate and Depth (winter data) in 75 wells

Because nitrate was the only parameter measured that was significantly correlated with depth (all other parameters were much more significantly correlated with aquifer and location suggesting geological rather than anthropogenic influences on levels), we assumed that nitrate levels were influenced by the type of land use surrounding the wells. Table 1 shows the correlations between the wells less than 15m deep and the surrounding land use. This table shows three important results. First, that there was a significant negative correlation between amount of forested land surrounding the wells and the amount of nitrate measured in the wells. This means that wells surrounded by more forest were less likely to have high levels of nitrate. Second, urbanized land (although a very small portion of the total land use in the valley) was significantly positively correlated with nitrate, meaning that wells surrounded by this land use were more likely to have high levels of nitrate than wells in other areas. Lastly, there was no correlation between the amount of nitrate seen in the wells and the area of agricultural land surrounding the wells.

Table 1. Spearman's Rank Correlation Coefficients (r): Land Use vs. Nitrate

Wells Correlated		Ag 50	Ag 100	Ag 200	For 50	For 100	For 200
<15 m	Winter	0.064	0.072	0.049	-0.425**	-0.449**	-0.440**
Deep	Summer	0.05	0.063	0.042	-0.469**	-0.448**	-0.464**
		Urb 50	**Urb 100**	**Urb 200**			
<15 m	Winter	0.315*	0.364*	0.449**			
Deep	Summer	0.471*	0.514*	0.521**			

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)
Ag 50-200 – the r value is a correlation between the % of agricultural land within 50 (or 100 or 200) m radius of a well and the amount of nitrate measured in the well.
For 50-200 (as above but for % of forested land within each radius of the well)
Urb 50-200 (as above but for % of urbanized land within each radius of the well)

Survey Results

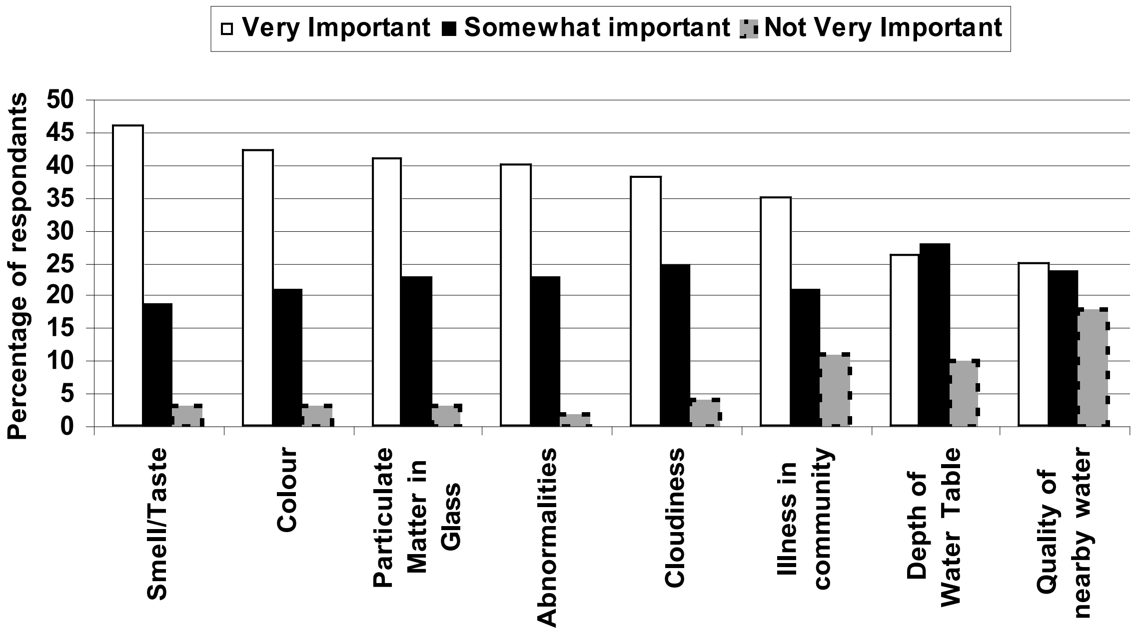

Figure 4. Aggregated responses to the question "How important are the following as a guide for indicating the quality of your water?"

Figure 4 shows responses to the question, "how important are the following as a guide for indicating the quality of your water?" Smell and taste, colour, and particulate matter in the glass were rated very important indicators by over 40% of respondents. Despite the previous result that showed that nitrate levels were highly related to well depth, less than 30% of respondents felt that depth of water table was an important indicator of water quality.

Table 2. Responses to "What is your perception of the water quality from

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your well?"					
	Excellent	**Good**	**Moderate**	**Fair**	**Poor**
Percentage	43%	36%	9%	7%	4%
Number	32	27	7	5	3

Table 2 shows the responses to the question "what is your perception of the water quality from your well?" A majority of respondents (79%) replied that they perceived their water quality to be excellent to good**.**

Table 3 shows the correlations between chemical parameters and the responses to the survey questions. Of note is the fact that perception of water quality was not correlated with nitrate level but was significantly correlated with iron level (fairly strongly) and less so (but still significantly) to Mn level.

Table 3. Correlation (Spearman's r) between Perceptions of Water Quality and levels of selected chemical parameters.

	NO_3-N	**Fe**	**Mn**
Perception of water quality	-0.161	0.417(**)	0.252(*)

Spearman's rank correlation coefficient (r)
(**) = Significant at α 0.01
(*) = Significant at α 0.05

Discussion

The results of the chemical analysis and the land use analysis showed that depth and percentage of urbanized land surrounding the well were the best indicators of potential nitrate contamination. The most important factor in determination of nitrate level was depth. All of the wells that had nitrate levels above 3 mg/L were less than 10m deep. This indicates that nitrate levels are likely largely determined by activity at the surface of the land. The next best indicator was the percentage of urban land surrounding the wells (again confirming the role of land use in determining nitrate levels). Although urbanized land makes up a very small (0.7) percentage of the total land use in the Hatzic Valley, these areas saw the majority of wells with nitrate levels greater than 3 mg/L.

The Hatzic Valley and the three aquifers studied are located directly north of Abbotsford, B.C., an area overlying what is acknowledged to be one of the most contaminated aquifers in Canada (Leibsher *et al.,* 1992; Zebarth *et al.,* 1998). This aquifer is contaminated with Nitrate widely acknowledged to be from agricultural sources (Leibsher *et al.,* 1992; Zebarth *et al.,* 1998, Carmichael et al, 1995). It was, therefore, somewhat surprising to find no links between agricultural land use and nitrate levels in the Hatzic Valley's aquifers. There are several reasons why this may have been the case. The type of agriculture practiced in the Hatzic Valley is not as intensive as that practiced elsewhere in the Lower Fraser Valley. There are no large chicken or pig farms nor are there large areas of intensive horticulture within 200 m of any of the wells sampled. Additionally, Hatzic Prairie, the area of the valley with the most agriculture, is also the area where the least groundwater samples were taken. The samples that were taken from this aquifer were largely clustered towards the north of the area where the land use is more mixed. This un-even sampling can largely be attributed to chance. Invitations to participate were sent to households throughout the watershed but there was limited control over the spatial distribution of those who agreed to participate. Residents also reported that surface water was a popular alternative to groundwater for domestic use in this area due to high iron levels in the groundwater.

Most residents of the valley felt their water quality to be "excellent" or "good" (79%). These results are not inconsistent with the results of the chemical analysis. However, when the perception was compared to the results of the chemical analysis there was a strong significant correlation between iron level and negative perceptions of water quality. As mentioned above, iron is a known nuisance chemical in water throughout the Hatzic valley. It stains pipes and causes bad odours and tastes; several wells within the study area exceeded the AO for iron. Iron is, however, not generally considered to be a health hazard. Nitrate on the other hand, was not correlated to water quality perception at all. Everyone who had high nitrate levels considered their water quality to be "good" or "excellent" and regularly drank their water. These results suggest that the residents based their water quality impressions on aesthetic indicators of quality rather than chemically determined ones.

In this study, depth was found to be the best indicator of nitrate level in water. No wells over 10m had nitrate above 3 mg/L. A disconnect between the results of the chemical and land use analysis and the survey results is seen again in the response to the question, "how important are the following indicators of water quality (see figure 4). " In this case depth to water table was not rated as highly important by a majority of people. Again, indicators such as taste and smell of the water were seen as much more important. Unfortunately nitrate is tasteless and odourless as are coliforms and other harmful bacteria.

Rural residents often have high trust in the quality of their water. This is true in the Hatzic Valley where 79% of residents perceive their water quality to be excellent or good. However, the perception of water quality in this area is not based on the results of laboratory tests, which can reveal risks such as nitrate and coliforms, but on tangible indicators of water quality such as taste and odour. By relying on such indicators residents may be missing "invisible" health hazards and unknowingly putting their families at risk. In the Hatzic Valley residents with shallow wells and those who live in urbanized areas should be aware that their wells are more vulnerable to contamination than deep wells located in forested areas and as such should ensure their wells are properly constructed and test their water more frequently. If problems are found, these well owners may have to consider treating their water or searching for alternate water sources.

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